# ANOMALOUS VARIATIONS IN THE ANGLE OF DOWN-COMING RADIO WAVES AND THEIR BEARING ON THE FADING OF SHORT WAVE SIGNALS

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**ABSTRACT.** It has been found that there are often anomalous variations in the angles of arrival of the down-coming radio waves from the ionosphere. A detailed study of the variations of intensity of short wave signals in the range between 16 m and 41 m bands, along with the simultaneous measurement of the angles of arrival of the down-coming waves, has therefore been made. The circumstances under which such anomalous variations resulting in abnormal values for the angle of arrival may be obtained, are discussed. It has been shown that when singly or doubly reflected waves are present, normal values of angles are obtained, which agree with the theoretically computed results. The anomalous variations and abnormal values of the angles have been explained to be due to the presence of ordinary and extraordinary rays arising from magneto-ionic splitting. This is borne out by the normal and fairly constant values of angle obtained when the extraordinary wave alone is present after disappearance of the ordinary wave component. A few examples of such observations have been given.

## INTRODUCTION

During our observations on the variation of intensity of short wave signals it was found useful to measure simultaneously the angles of arrival of the down-coming waves in order to obtain information about the exact region of the ionosphere which was responsible for the reflection of these waves. The results of such observations have been briefly stated in some of the earlier publications from this laboratory (Banerjee and Mukherjee, 1946, 1948; and Banerjee and Singh, 1948). A detailed study of such observations, however, reveals that there are very often anomalous variations in the angles of arrival of the down-coming waves which are associated with abnormal values of these angles. It is the purpose of this paper to discuss the various circumstances under which such anomalous results are obtained, and also when normal values of the angles are observed. The correlation between the variations in the angles of arrival and the intensity of the received signals has been shown and its importance in finding out the conditions of the ionosphere for the suitability of the frequency which may be employed for transmission at oblique incidence has been indicated.

## THEORETICAL CONSIDERATIONS AND EXPERIMENTAL ARRANGEMENTS

The method adopted for the measurement of the angle of arrival of the down-coming waves is similar to that used earlier in this laboratory by

Banerjee and Mukherjee (1948). For clarification, however, a brief summary of the principles of the method and the experimental arrangement is given below.

In this method, the mutually perpendicular electric and magnetic fields associated with the down-coming wave are received separately by a vertical and a frame aerial (Appleton and Barnett, 1925) connected to two superhet receivers as shown in block diagrams in figures 1 and 2. Taking into

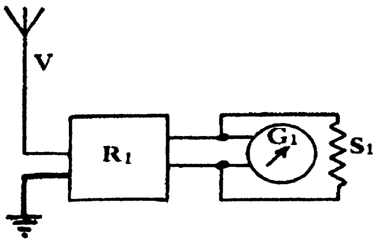



FIG. 1

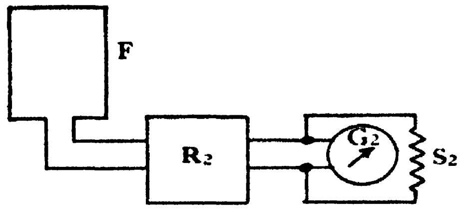



FIG. 2

account the absence of ground wave at the present working range of distance, a simple formula connecting signal currents due to the two aerials and the angle of arrival can be derived as shown below.

If $I$ be the mean total current in the detector circuit connected to any of the aerials, and $A$ and $K$ be the constants of the aerial and the detector respectively, it can be shown that,

$$I_v = 2A_v K_v E \cos\phi \qquad \ldots \quad (1)$$

and,

$$I_f = 2A_f K_f H \qquad \ldots \quad (2)$$

where the suffixes $v$ and $f$ relate to the vertical and the frame aerials. $E$ and $H$ are the electric and magnetic vectors associated with the down-coming wave whose front makes an angle $\phi$ with the ground.

Let $G_1$ and $G_2$ be the resistances of the galvanometers and $S_1$ and $S_2$ those of the shunts across them as shown in figures 1 and 2. If we denote the currents in the galvanometers by $i_1$ and $i_2$, then,

$$i_1 = I_v \cdot \frac{S_1}{S_1+G_1} = 2A_v K_v E \cos\phi \cdot \frac{S_1}{S_1+G_1} = K'.d_1 \qquad \ldots \quad (3)$$

$$i_2 = I_f \cdot \frac{S_2}{S_2+G_2} = 2A_f K_f H \cdot \frac{S_2}{S_2+G_2} = K''.d_2 \qquad \ldots \quad (4)$$

where $d_1$ and $d_2$ are the deflections in the galvanometers produced by the rectified currents, and $K'$ and $K''$ are the current constants of the galvaname-ters. Dividing eqation (3) by (4) we get,

$$\frac{K'}{K''} \quad \frac{d_1}{d_2} \quad \frac{2A_v K_v E \cos\phi}{2A_f K_f H} \quad \frac{S_1}{S_1+G_1} \quad \frac{S_2+G_2}{S_2}$$

$$\text{or } \frac{d_1}{d_2} \quad \frac{K''}{K'} \cdot \frac{A_v}{A_f} \cdot \frac{K_v}{K_f} \cdot \frac{S_1(S_2+G_2)}{S_2(S_1+G_1)} \cdot \frac{E}{H} \Big\} \cdot \cos\phi \qquad \ldots \quad (5)$$

Now, since $E \equiv H$ in proper units, and all other terms within the brackets are constant so long as the shunts are the same, we have,

$$\frac{d_1}{d_2} = K \cos \phi \qquad \dots \quad (6)$$

It may, however, be noted that the above deductions have been made on the assumption of linear characteristics of the two detecting circuits as used in the present receiving sets. In actual measurements, however, $K$ is made equal to unity by adjusting the shunts so that the overall sensitivities of the two receiving systems may be equal.

In the present investigations two similar superheterodyne receivers without automatic volume control systems were used as the detectors. Suspended coil mirror galvanometers were connected in the second detector stages of the two receivers and the deflections were measured by lamp and scale arrangements. For making adjustments for the sensitivity, as mentioned above, a valve oscillator was placed at the same height as the two receivers at a sufficient distance away from them. The output of the oscillator was fed to a vertical aerial of suitable height. The direct pick-up of the signal, particularly by the frame aerial, was thus considerably minimised. The values of the shunts were then adjusted till the deflections in the two scales were equal after allowing for the deflections due to the noise levels in the sets. As the ground wave alone is present in the above experiment, the angle of arrival of the waves at the receivers is zero and thus $\cos \phi = 1$. Now, when $d_1$ is made equal to $d_2$, the value of $K$ in equation (6) becomes equal to unity, and we get,

$$\frac{d_1}{d_2} = \cos \phi \qquad \dots \quad (7)$$

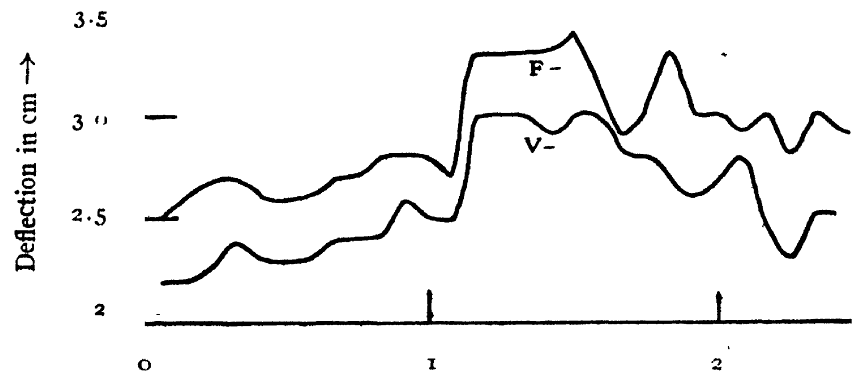
The adjustment of the shunts for the above conditions was verified by elevating the oscillator with its aerial system to a measured height. The deflection in the galvanometer with vertical aerial decreased, and the angle of elevation obtained from the deflections $d_1$ and $d_2$ by equation (7) was verified by the actual angle obtained from the distance and height of the oscillator.

As the sensitivities of the two receivers did not remain the same for all the frequency bands, the above adjustments were made for various wave bands used in the present investigations.

## OBSERVATIONS

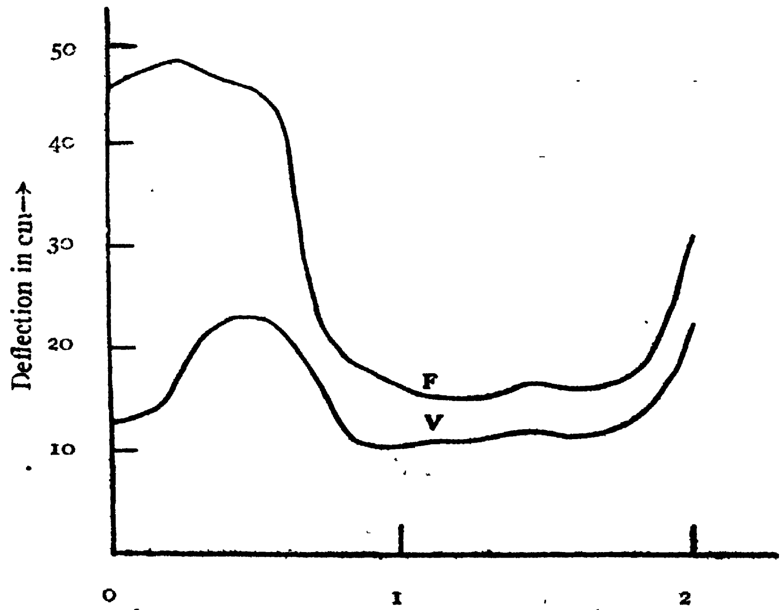
Observations were taken at various hours of the day and night and on various wave lengths in the range of 16m to 41m bands, especially for the transmissions from Delhi. The variations of the angles of arrival and the corresponding variations of intensity have been divided into four different types depending on the number of reflections from the ionosphere. It has been observed that the angle of arrival is fairly constant and the variations of the angle are also normal as long as there is only single reflection from the ionosphere. The variation of the angle of arrival increases with the occurrence of more than one reflection and anomalous results are obtained when there are two components of the wave due to magneto-ionic splitting. Based on the above considerations the four different types of observations mentioned above are under the conditions shown below.

1. *Single reflection at conditions remote from the maximum usable frequency (m. u. f.)* Figure 3 gives the observations for transmission from Karachi in morning hours (0749 I. S. T. on 13.10.50.). The variations of intensity in the vertical and frame aerial systems are marked *V* and *F* respectively. The angle of arrival obtained was about 20°.




Karachi, 19m band ; 13. 10. 50 ; 0742 Hrs, I. S T

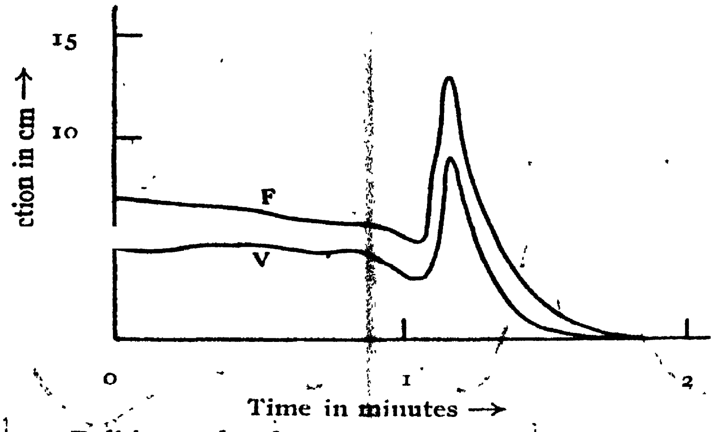
FIG. 3




Delhi, 16m band, 14. 10. 50; 1845 Hrs ; I. S. T.

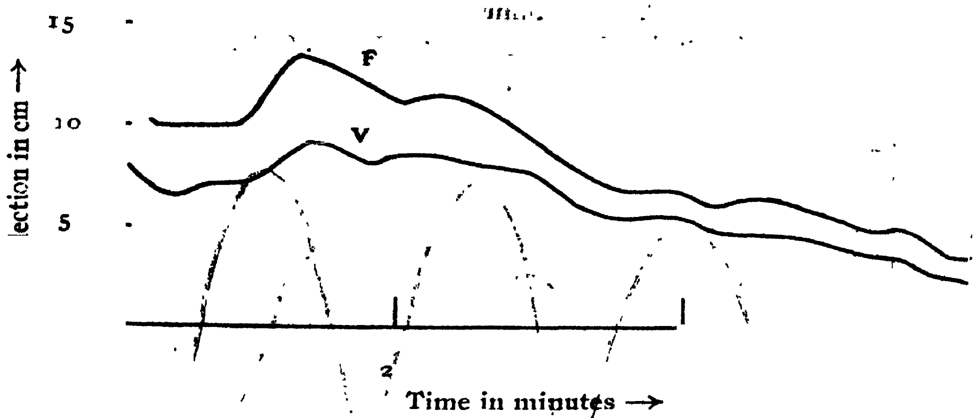
FIG. 4

2. *Single reflection due to extraordinary ray only at conditions very near m. u. f.* Figures 4 to 7 show similar observations as above for transmissions from Delhi. The various types of fading patterns under this condition have been discussed in detail in the subsequent section.



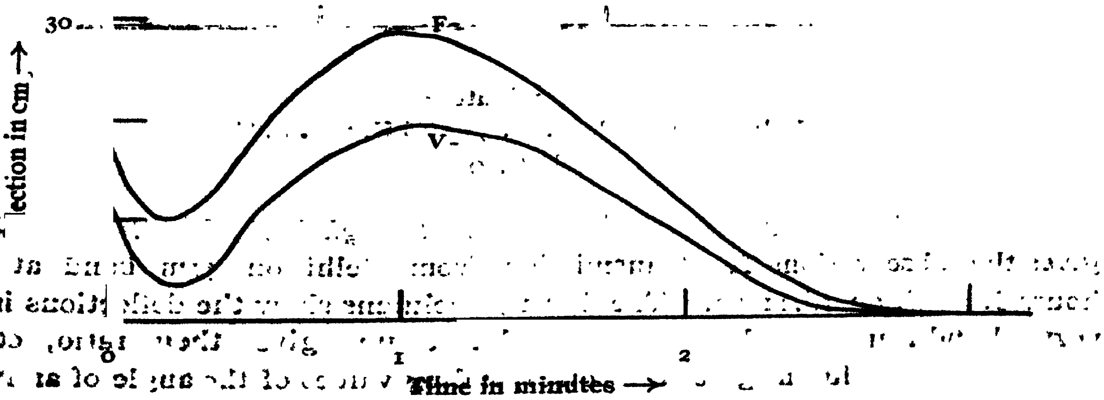

Delhi, 19m band, 24. 10. 50; 1745 Hrs; I. S. T.

FIG. 5



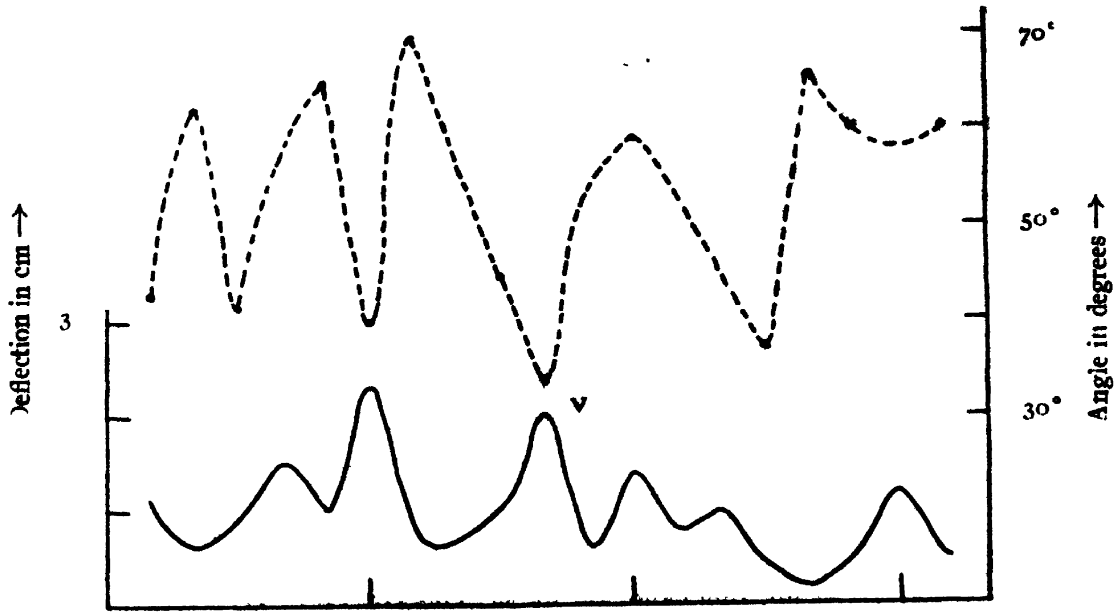

Delhi, 41m band; 26. 10. 50; 2000 Hrs; I. S. T.

FIG. 6

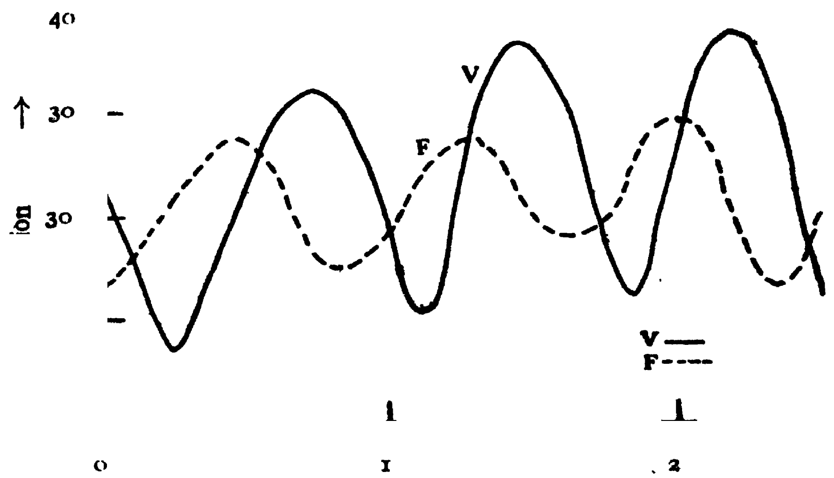



Delhi, 19m band, 12. 10. 50; 0820 Hrs; I. S. T.

FIG. 7




Time in minutes →
Delhi, 31m band, 5. 9. 50; 1945 Hrs; I. S. T.
FIG. 8




Time in minutes →
Delhi, 16m band, 14. 10. 50 1316 Hrs; I. S. T.
FIG. 9

3. *Single and double reflections due to high ionic densities.* Table I gives the observations for transmission from Delhi on 41m band at 0928 hours I. S. T. on 16.11.50. The first t. o columns show the deflections in the vertical and frame aerial systems; the third column gives their ratio, cos $\phi$, and the last column gives the corresponding values of the angle of arrival $\phi$. The curves in figure 8 show the variation of intensity in the vertical aerial system and the variation of the angle of arrival.

TABLE I

Time Interval : 5 seconds.

| $d_1$ (cm.) | $d_2$ (cm.) | cos $\phi$ | $\phi$ (degrees) |
|---|---|---|---|
| 8 | 13 | 0.62 | 52 |
| 11 | 18 | 0.61 | 52.5 |
| 15 | 24 | 0.63 | 51 |
| 14 | 23 | 0.61 | 52.5 |
| 11 | 15 | 0.73 | 43 |
| 9 | 16 | 0.56 | 56 |
| 12 | 14 | 0.86 | ... |
| 11 | 17 | 0.65 | 49.5 |
| 18 | 37 | 0.5 | 60 |
| 22 | 29 | 0.75 | 42.5 |
| 12 | 18 | 0.67 | 48 |
| 14 | 26 | 0.54 | 57 |
| 18 | 26 | 0.7 | 45 |
| 14 | 18 | 0.78 | 40 |
| 14 | 21 | 0.67 | 48 |
| 11 | 13 | 0.85 | ... |
| 13 | 20 | 0.65 | 49.5 |
| 10 | 14 | 0.71 | 45 |
| 12 | 21 | 0.57 | 55 |
| 12 | 29 | 0.41 | 65.5 |
| 14 | 21 | 0.67 | 48 |
| 14 | 27 | 0.52 | 59 |
| 16 | 22 | 0.73 | 43 |
| 16 | 24 | 0.67 | 48 |
| 14 | 23 | 0.61 | 52.5 |
| 13 | 28 | 0.47 | 62 |
| 14 | 24 | 0.58 | 54 |
| 9 | 15 | 0.60 | 53 |
| 11 | 22 | 0.50 | 60 |

4. *Anomalous variations in the angle of arrival due to magneto-ionic splitting.* A typical set of observations of the above type are shown by the curves *V* and *F* in figure 9. The dotted curve *F* shows the intensity variation in the frame and the full line curve *V* shows the variation in the vertical aerial.

The observations in all the above sets have been taken at intervals of 5 seconds (except in the case of those relating to figure 8 where the interval was 10 seconds), simultaneously in the vertical and frame systems. The correlation between the variation of intensity and the angle of arrival has been discussed in the following section.

## DISCUSSION OF RESULTS

The following discussions are based on the above four types of observations.

1. When the operating frequency is far away from the m.u.f., towards the lower side, only one reflected wave is present and the variations of signal intensity in both frame and vertical aerials are small and in phase, giving a sensibly constant value of angle that agrees with the calculated angle for waves from the transmitting station reflected from layers whose heights are known from ionospheric data. The intensity patterns for both vertical and frame aerials in figure 3 show a slow rate of variation. The value of the angle obtained (20°) is consistent, and this corresponds to a height of 350 Km. It may be mentioned that as the layer is fairly thin in the morning the magneto-ionic components are not pronounced.

2. When the ionic density is so low that the working frequency is very near the m.u.f. for that density, there is no possibility of double reflection. Hence when the ionization is falling, the condition is reached when the ordinary ray can no longer be reflected. After the disappearance of the ordinary ray, only the extraordinary ray arrives and gives rise to single wave reception. Under this condition, a constant value of angle is obtained. The extraordinary ray, however, may also disappear subsequently, as shown in figures 5 and 7.

It will be seen in figure 4 that just before 1846 hrs IST a hump appeared in both *V* and *F*, a peak of intensity, which was more pronounced in *F*. This signifies the disappearance of the ordinary ray. Thereafter the variations of intensity became smooth, in phase, and a consistent value of the angle (44°) was obtained, showing the presence of the extraordinary ray only. Had the station continued this might also have disappeared with its final peak of intensity due to 'focussing effect', as indicated by the rising trends of the two curves. But the station was tuned off the air at 1847 hours. This later stage of disappearance of the extraordinary ray was noticed in Delhi 19 m-band at 1746 hours IST on 24th October, 1950, shown in figure 5. Here the *V* and *F* deflections were almost steady for 3 minutes. Their ratio led to an angle of 45° during all this interval and also at the peak of intensity in both, after which the signal disappeared. Figure 6 shows a very slow and gradual rate of fading of the extraordinary ray Delhi 41 m. signal on 26th October, 1950, beginning at 2000 hours IST. The graphs have been drawn on a contracted time scale, to bring out the slow rate of fading over a large period of time. All along, a value of 45° was obtained for the angle. Actually the intensity fell down and continued at a low level for more than an hour.

Figure 7 is an interesting pattern of fading. In the morning time the disappearance may be attributed to the over-balancing of the growth of ions by thermal expansion of the layer (Banerjee and Singh, 1949). This may be seen in the slow and long-drawn out pattern of the final hump before disappearance of the extraordinary ray and during which period a constant angle of 45° was observed.

It may be noted that these disappearance phenomena were observed to occur more frequently in the lower wavelength bands (16 and 19 m) and shorter distance stations, that is, of signals from Delhi but not from Karachi or Ceylon.

3. If the electronic density in the ionospheric layer is sufficiently high, rays from the transmitter can reach the receiver by single and double reflections both. It may be seen that many of the values of angle, given in column 4 of Table I, centre round the value 47°; this corresponds to single reflection. A smaller number of values comes out around 6°, which corresponds to double reflection. The remaining values fall between these two limits. It may be seen that there are no abnormal values of cos $\phi$ whose occurrence is a marked feature of magneto-ionic variations of intensity as mentioned previously. In Fig. 8, the general coincidence of a lower intensity of signal when the angle corresponds to double reflection and higher intensity when the angle corresponds to single reflection may be noticed. Also, the observations indicate which reflection is predominating and what are the modes of variation of intensity of singly and doubly reflected waves. Thus, it will be seen in figure 8 that at the beginning of the observations, second reflection was of higher intensity than the first but towards the end the intensity of doubly reflected waves was generally weak. It may be mentioned that such double reflections have been observed during pulse transmissions from Delhi. The exact nature of the contribution of the doubly reflected wave to the angle is, however, discussed below.

It can be shown theoretically how much the measured angle will be nearer to the value corresponding to the more predominant reflection, assuming the path difference between the rays arriving by single and by double reflection to be constant, and that there is no appreciable vertical movement of the layer to affect the angle of incidence. Let the electric and magnetic vectors associated with the singly and doubly reflected waves be $E_1$, $H_1$ and $E_2$ $H_2$ respectively, and the angles of arrival of these waves be $\phi_1$ and $\phi_2$. As the field strength at the receiver will be the vector sum of those due to the individual waves, the total fields causing deflections in the vertical and frame aerial systems are respectively, $E_1 \cos \phi_1 + E_2 \cos \phi_2$ and

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$H_1 + H_2$. We may assume that the ratio between the two vectors $E_2/E_1 = k$ which may vary. As all other conditions are the same, we can write equation (7) as.

$$\frac{d_1}{d_2} = \frac{E_1 \cos\phi_1 + E_2 \cos\phi_2}{H_1 + H_2} = \frac{E_1 (\cos\phi_1 + k\cos\phi_2)}{H_1 (1+k)} = \frac{\cos\phi_1 + k\cos\phi_2}{1+k} \tag{8}$$

According to the ratio of deflections we will get an angle $\phi_3$ say, such that

$$\cos\phi_3 = \frac{d_1}{d_2} = \frac{\cos\phi_1 + k\cos\phi_2}{1+k}$$

Thus the measured angle will depend on the value of $k$.
For illustration, let $\cos\phi_1 = 0.7$ and $\cos\phi_2 = 0.5$, corresponding to the angles 45° aud 60° respectively. Then,

$$\cos\phi_3 = \frac{0.7 + 0.5k}{1+k}$$

For different values of $k$, we get different angles as shown in Table II below :

TABLE II

| $k$ | 0 | $\frac{1}{4}$ | $\frac{1}{2}$ | 1 | 2 | 5 | 10 | $\infty$ |
|---|---|---|---|---|---|---|---|---|
| $\cos\phi_3$ | 0.7 | 0.66 | 0.63 | 0.60 | 0.57 | 0.53 | 0 52 | 0 5 |
| $\phi_3$ (degrees) | 45 | 48.5 | 51 | 53 | 55 | 58 | 59 | 60 |

A fractional value of $k$ means that the doubly reflected wave is weaker. A value of 0.6 for $\cos\phi_3$ means that the two are of equal intensity. Thus, if either the first or the second is more strong, the angle will change correspondingly. Since in general the chances are more for the intensity of a singly reflected wave to be greater than that of one arriving by double reflection, the occurrences of angle corresponding to double reflection should be fewer than for single reflection and this is found to be so.

4. Due to the effect of the earth's magnetic field, the incident wave in the ionosphere is split into ordinary and extraordinary waves, and the difference in the reflected intensities and phases of these two rays is more pronounced when the ionic density is low. The variations of intensity due to interference between the two rays give rise to an interference pattern as shown in figure 9. Such a type of fading is accompanied by wider and more rapid fluctuations in the vertical than in the frame system of aerials. There also appears a large difference in phase in the variations of the two intensities as will be observed in the figure. Further, abnormal values of the angle of arrival are obtained when the intensity in the vertical aerial is too high or too low compared to the intensity in the frame aerial.

## SUMMARY

Simultaneous observations have been recorded for the angles of arrival of the down-coming waves and the variations and abnormal values of the angles of arrival have often been observed which have been explained to be due to the presence of magneto-ionic split components of the waves in the ionosphere. It has been further shown that normal values of angles of arrival are obtained when the waves mainly undergo single or double reflections from the ionized layer. The above conclusions have been varified for single reflection when the extraordinary wave alone is present.



## ACKNOWLEDGMENTS

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